U. S. ARMY TEST AND EVALUATION COMMAND
BACKGROUND DOCUMENT

MISSILE FLIGHT SURVEILLANCE

1. INTRODUCTION

Currently, missile and rocket systems undergo engineering tests under the consolidated or integrated concept of testing rather than under the sequential test approach. Under the integrated concept, analyses of test requirements are carried out during the earliest practicable stage in the development of the system. Through these analyses, it may become apparent that data requirements for engineering tests may be fulfilled during engineering design or other early tests. Missile flight surveillance is concerned with the static firings and flight tests of flight vehicles throughout their life cycle.

By their very nature, missiles and rockets are hazardous. Their flight range capabilities with respect to their impact points vary greatly; and in their earlier development phases, their behavior in flight is not entirely predictable. Urgency in testing requirements, high costs of tests, unwillingness to accept costly testing delays, and overall characteristics of missiles and rockets create the need for an independent means of assuring safe impacts at all times.

For the purposes of this discussion, missile flight surveillance embraces all those functions of an established missile range which together constitute an independent means of assuring safe impacts at all times. Missile flight surveillance develops and/or approves each of those functions, which are essentially as follows:

a. Develops safety criteria for each program prior to acceptance of its vehicle(s) for testing.
b. Determines the scope and sophistication of missile flight surveillance required for each program depending on vehicle system capability.
c. Provides or develops the surveillance method or process which results in knowledge of a vehicle's flight parameters in real time.
d. Determines which vehicle characteristics to measure to assure safe impacts of vehicles tested.
e. Establishes critical range parameters for vehicles tested.
f. In overland operations designates special areas for abort conditions.
g. In overland operations, designates special areas for booster impacts.
h. Precalculates terminate criteria.
i. Develops terminate systems.
j. Approves integral failsafe systems.
k. Performs analysis of vehicle recovery systems.
l. Defines communications requirements.

m. During missile firing test operations contributes a Green-Light input to Central Range Control Station.

n. Prescribes means to reduce or eliminate human error in interpretation of terminate data.

Aside from the foregoing considerations, the following reasons show the need for missile flight surveillance:

a. Within established ranges there exist sensitive areas which must be safeguarded against vehicle impacts.

b. Areas outside established missile ranges must not be indangered be vehicle impacts.

c. Critical ranges wherein damage may occur to land, facilities, or personnel must be especially safeguarded against vehicle impacts.

d. Vehicles impacting beyond established missile ranges may cause no actual damage; however such impacts may result in embarassment and/or adverse publicity to testing authorities. Therefore, impacts in such areas must be prevented.

e. Vehicles whose flight range capabilities lie wholly within established ranges must be prevented from impacting in range sensitive areas.

f. Vehicles whose flight range capabilities are beyond established ranges must be prevented from impacting either beyond their critical ranges or in range sensitive areas.

g. Vehicles whose flight range capabilities lie within established ranges may require surveillance for other than unsafe impact considerations.

1) Vehicle may carry toxic matter; therefore its impact area must be known precisely for decontamination.

2) Vehicle may carry classified material; therefore its impact area must be known precisely for recovery and/or destruction of the classified material.

h. Within the continental United States, established missile range boundaries may include or be adjacent to lands under the jurisdiction of the Department of Interior or similar agency whose safety requirements must be met, and over whose territory vehicle impacts must be strictly controlled and/or totally prevented.

2. ANALYSIS

The envelope of expected performance of the flight vehicle determines the scope and sophistication of missile flight surveillance required for each program. The performance is assessed against (1) geographical boundaries and limitations, (2) the ability to accept consequences of malfunctioning vehicles, (3) the ability to make adequate performance measurements, and (4) the ability to take actions which will change or minimize nonacceptable consequences.

Preliminary analyses are accomplished by formulating a matheti-cal model of vehicle performance. The important contributing parameters which could lead to nonacceptable consequences are allowed to vary until the worst conditions are reached. However, it is not reasonable to carry the investigation into the realm of theory where physical laws cannot hold true. When it is determined that the mathematical approximation can take place within the performance potential of the vehicle, the results of these analyses lead to the development of the safety criteria for each program. The mathetical model studies can also provide clues as to which performance parameters must be measured to derive estimates of the time during which vehicle impacts can be influenced by deviations.

3. MEASUREMENT REQUIREMENTS

The overall measurements requirements of missile flight surveillance calls for making independent vehicle performance measurements. This is a means of assuring safe impacts at all times. However, these overall requirements may not be a necessity for all situations. Tactital systems which contain some real time performance outputs may provide sufficient information to permit flight safety decisions. As a rule, data from non-independent performance measurement systems may be used if such data is qualified by comparison with some independent measurement system.

A close inspection of the mathematical model will show that there are many variables which can be measured, each of which can have an effect on vehicle impact. Any of these variables measured in real time and plotted against each other or against other variables can provide adequate data. Similarly, where attitude or functions can be telemetered in real time, the vehicle itself provides a valuable source of measurements for use in making flight safety decisions.

While there are no standard measurements of vehicles in flight which will guarantee flight safety, there are several guidelines to be observed in choosing measurement systems for missile flight surveillance.

a. Accuracy of the final result must be consistent with the accepted consequence. For example, when protecting a boundary, if a one-mile overshoot is unacceptable, the measurement system must have a resolution of better than one mile.

b. Where possible, human judgment should be left in the system and data interpreted by trained human operators.

c. Allowance must be made for the response time of individuals acting as flight safety officers.

d. Vehicle parameters to be measured and accuracies required are governed by the type of vehicle, its performance characteristics, and its range capability.

e. Instruments for measuring or predicting vehicle impact locations to within small errors (for vehicles with range only flight capabilities) are:

(1) Radars
(2) Doppler
(3) Infrared
(4) Airborne radio transmitting devices
(5) Flares
(6) Special telemetry packages

4. COORDINATION REQUIREMENTS

Missile flight surveillance has the one essestial aim of assuring safe impacts at all times. However, the functions for achieving this result are many. Therefore the dependency of missile flight surveillance on other facilities of an established missile range is quite extensive. As a minimum, missile flight surveillance is dependent on other facilities for communications, real time information display, radars, telemetry, and meteorological support. This dependency, in turn, places many coordination requirements and the means for effecting them as very important factors in the successful accomplishment of missile flight surveillance.

A further area which requires extensive coordination is that presented by problems associated with vehicle surveillance. Some of the more salient ones are (1) vehicles containing devices which impose restrictions of surveillance capability; for example, vehicles using x-bank in their guidance system preclude its use in tracking; (2) poor reliability of certain devices used as tracking aids; (3) nonavailability of more reliable tracking devices.

5. COMMUNICATIONS REQUIREMENTS

The successful accomplishment of missile flight surveillance functions during countdown procedures and post-firing operations necessitates certain communications requirements. Aside from normal communications means, a special communications network must be available to enable all coordinating personnel, including meteorological support personnel, to be in voice contact during operations.

6. SAFETY CONSIDERATIONS

Various flight vehicle characteristics, flight environment phenomena, and ground equipment capabilities are of special concern to missile flight surveillance. Some of these considerations are (1) flight range capability, (2) toxicity of propellants or of on-board materials, (3) vehicle fragmentation capability, (4) inherent vehicle stability, (5) temperature inversion and its effect on ability to track with radar, (6) winds and jet stream

phenomena, (7) power failures and back up systems, (8) general redundance as increase in reliability factors.

Safe impacts can be effectively achieved by (1) choosing certain cones of fire which impose azimuth and elevation limits, (2) providing a means of discontinuing vehicle flight, (3) providing a means of nullifying adverse conditions which might develop, (4) providing an on-board terminate system, (5) providing a means of instantaneously detonating the on-board terminate system, (6) providing a means for limiting vehicle flight range, (7) providing the vehicle with a control system such that the vehicle is caused to stop, turn, or dive upon command from a remote control station.

7. TEST VEHICLES

Flight vehicles of concern to missile flight surveillance fall into four main types (1) research vehicles, (2) weapons systems vehicles, (3) nonpiloted drone aircraft, and (4) motors for static firings.

Research vehicles are flying laboratories instrumented to measure atmospheric conditions or exoatmospheric phenomena. Overall characteristics of research vehicles of concern to missile flight surveillance are (1) they can attain altitudes in excess of 100 miles, (2) they do not incorporate guidance systems, (3) they are wind pointed and very wind sensitive, (4) they may be balloons or rocket probes, (5) they record data by means of RF transmitting devices or by recovery of vehicleborne recording equipment, (6) they are accurate since a small error in estimating wind behavior can result in an off range impact.

Weapons systems vehicles carry various design warheads to specified points in space or on the ground for the accomplishment of required military missions. Overall characteristics of weapons systems vehicles of concern to missile flight surveillance are (1) overland operations vehicles attain ranges of over 400 miles, (2) nonoverland vehicles attain ranges of 70 to 90 miles, (3) guidance system malfunctions can be expected, (4) guidance system malfunctions can result in off range impacts, (5) guidance malfunctions can result in impacts endangering highways and/or other sensitive areas, (6) surface-to-surface vehicles may attain beyond range flight capability under malfunction conditions, (7) surface-to-air vehicles permit limiting their impact range by azimuth and/or elevation restrictions, (8) surface-to-air vehicles may attain beyond range flight capability under malfunction conditions, (9) air-to-surface vehicles may attain beyond range flight capability under malfunction conditions, (10) air-to-air vehicles have limited range flight capabilities, (11) warheads tests on any of the vehicles may pose recoverability problems when security is involved.

Nonpiloted drone aircraft are essentially targets for surface-to-air and/or air-to-air weapons systems vehicles. Overall characteristics of

these aircraft of concern to missile flight surveillance are (1) cruising speed and altitude, (2) maximum turn capability, (3) endurance capability, (4) tracking aids such as transponders, antennas, and bright colorings, (5) recovery sequence, and (6) parachute descent rates.

Motors for static firings are propulsion sections or portions of propulsion sections of any proposed vehicle. Missile flight surveillance must insure that the holding devices hold the motor so that it cannot become separated from its restraining bonds during its static firing. Overall characteristics of these motors of concern to missile flight surveillance are revealed in the reasons for static firings. Some of these reasons are (1) never having tested the motor previously, (2) rechecking of motors because of malfunction experienced in flight, (3) to obtain vibration characteristics, (4) to obtain a thrust-time relationship, (5) to measure motor tail-off phenomena, and (6) to measure thrust misalignment.

8. FLIGHT TERMINATION SYSTEMS

It bears repeating that missile flight surveillance embraces those functions of an established missile range which together constitute an independent means of assuring safe impacts at all times. Once a vehicle is launched, safe impacts can be effectively achieved by providing a means for limiting vehicle flight range. One of the ways for its accomplishment is by use of flight termination systems.

A flight termination system is a means of destroying or (as is more commonly said) "destructing" a vehicle. Termination can be carried out in various ways; therefore, "terminate" has several meanings.

a. Terminate may be synonymous with disintegrate: the vehicle is shattered, utterly destroyed into many small fragments which can cause negligible damage on impact.

b. Terminate may be equivalent to separate: the vehicle is separated or broken up into only two or three unstable pieces which fall quickly.

c. Terminate may mean motor shut off: the vehicle's propulsive force is disabled, so that thenceforth the vehicle follows a ballistic path.

d. Terminate may be the same as disable: the firing circuit of a stage in a multistage vehicle is rendered inoperative.

e. Terminate may mean abort: the vehicle is either destroyed by disintegration close to its launcher, or its ignition system is disabled such that launching is prevented at the very last moment.

f. Terminate may mean "severance": in upper altitude research vehicles to effect separation of payloads from final stages

g. Terminate may mean effect recovery command: in upper altitude research vehicles to permit recovery command transmission via flight surveillance equipment.

Irrespective of their functions, flight termination systems fall into three broad categories: precommand and command terminate systems, failsafe

systems, and recovery systems.

Precommand terminate systems are generally timed terminate systems. In these systems a specified time after launch is precalculated. The terminate system in the vehicle incorporates a timer, which is set prior to launch, is initially enabled when the vehicle is launched and actuates the terminate system at the specified time after launch.

In the command terminate systems, ground control transmits a signal for termination, and the terminate system receiver in the vehicle initiates the terminate train upon receipt of the transmitted command. Therefore, from the overall standpoint of missile flight surveillance, command terminate systems involve special coordination requirements.

a. Installation of terminate system receiver and detonator block must be incorporated with the checkout and countdown procedures.
b. Command terminate transmitter, regardless of its physical location relative to the vehicle, must be a part of the countdown for the purposes of checking out the receiver once it is installed.
c. Last minute checks include vehicle site checkout personnel, command terminate transmitter personnel, and real time information display center personnel.

Command terminate systems are activated on command. For this to occur, certain data requirements must be fulfilled.

a. Predetermination of the nature of "x-distance" ; i.e., whether it is a constant or variable with altitude and velocity.
b. Precalculation of x-distance.
c. Real time vehicle position.

(1) When vehicle is x-distance from a range boundary.
(2) When vehicle is x-distance along the flight line from a sensitive area.
(3) Vehicle position and altitude at all times.

d. Measurements of components of velocities.
e. In flight time.
f. Post-ignition elapsed time.
g. Coast times between burnout of one stage and ignition of next stage.
h. Description of vehicle attitude between stages.
i. Drawing of precalculated terminate criteria on real time information display.

As indicated for data requirements, command terminate systems have certain instrumentation requirements which must be provided in order that

missile flight surveillance may fulfill its functions.

a. Tracking radar
b. Velocimeter
c. Analog or digital computer ground equipment in association with radar.
d. Sensitive ground receivers for vehicleborne transmitting instruments.
e. Ground equipment timing devices
f. Ground equipment timing station
g. Analog time ramps in conjunction with timing station.
h. Data presentation and/or recording means.

(1) Ground equipment strip chart recorders.
(2) Ground equipment analog plotting board.
(3) Real time information display.

In the failsafe systems, weapon system ground surveillance equipment transmits a signal during normal system operation, which disables or negates the terminate system. When ground surveillance is lost whether by malfunction or design, the terminate system is enabled; the terminate train is initiated; and the vehicle is destructed either by disintegration, separation into two or three unstable pieces, or by effecting motor cut off.

From the overall standpoint of missile flight surveillance, failsafe systems present somewhat different problems from those discussed regarding command terminate systems.

Failsafe systems are an integral part of the vehicle design, generally intimately associated with the guidance sections of the weapon systems. Therefore the installation of failsafe systems and their special features are approved, but neither installed nor designed by missile flight surveillance. Some of the problems of these systems of concern to missile flight surveillance are outlined below:

a. Vehicle antennas
b. Vehicle tracking devices
c. Vehicle tracking aids

(1) Beacons
(2) Transponders
(3) Brightly colored portions of vehicles
(4) Vehicleborne lights

d. Coordinated system for vehicle tracking
e. Real time information display

(1) Analog Form
(2) Digital Form
(3) Plotting board grid
(4) Strip chart recorder

f. Special terminate transmitters and associated hardware which control the ground equipment surveillance tracking and negating terminate system signal to the vehicle.

g. Communications network for responsible observers and command terminate transmitter stations. These networks may require the capability for issuing a terminate command by voice or by triggering a terminate transmitter remotely from the real time information display center. In turn these commands must cause weapon system surveillance equipment to slew away from the vehicle, cease tracking, or discontinue the negating signal.

Recovery systems normally involve payloads in research vehicles, and nonpiloted drone aircraft. Sometimes recovery systems may be installed in post-test investigations and analyses. Recovery systems for vehicles other than nonpiloted drone aircraft incorporate provisions for severance of payloads plus some means of parachuting or safe delivery of payload to its impact point. Recovery systems for nonpiloted drone aircraft incorporate provisions for disabling aircraft power and for safe delivery of the aircraft as its impact point.

Recovery systems call for essentially the same requirements as those involved in command terminate systems. The appropriate vehicleborne recovery system is installed; its functions are checked out as part of the countdown procedures; a remote control device is established at the real time information display center; and command to initiate recovery is issued at the precalculated and/or optimum time. The recovery system on board is activated, causing vehicle severance and parachute ejection or disablement of aircraft power and release of its parachute.

GLOSSARY

1. Abort Conditions: Early malfunction requiring termination, and causing the vehicle to impact within a prescribed zone known as the "Abort Area". In general this includes the immediate vicinity in front of the launcher and, depending upon the type and performance capability of the vehicle may extend several miles in a wide cone in front of the launcher.

   Abort can also mean a malfunction which prevented a continuation of the countdown owing to the failure of a component to pass test requirements during its alloted checkout period.

2. Booster Impacts: First stage impacts or impact areas.

3. Critical Range: That range at which or beyond which impacts may or will cause damage to areas within an established missile range or off the range.

4. Endurance Capability: That property of a flight vehicle which is a measure of its capacity to stay airborne. This capability is measured in units of time.

5. Established Missile Range: An installation organized for the purpose of firing and/or testing missiles. This includes administrative areas, launch sites, instrumentation sites, associated equipment essential to the carrying out of proposed firings and the real estate,purchased or leased, used as impact areas for the vehicles. These areas can be in the United States, in foreign countries, or over neutral areas such as the oceans.

6. Failsafe Systems: Integral missileborne equipment operating under the condition that the loss of signal from some ground or air operated radio frequency device will cause the flight termination system to activate.

7. Flight Parameters: Position, velocity, acceleration, attitude, coordinated with time.

8. Flight Range Capability: In general, the maximum ground range which a vehicle can be expected to attain under the most favorable conditions for the vehicle flight.

   All ranges up to and including this maximum range. Thus also an area extending from the launcher in all directions which the vehicle can physically attain.

9. Flight Safety: The carrying out of missile flight surveillance during active flight of a vehicle whether in real time or as a precalculated study.

10. Flight Termination System: A system which when activated produces consistently predictable behavior modes and/or impact dispersions.

11. Flight Vehicles: Any vehicle capable of flight upon release from launching restraints.

12. Impact Point: The actual or intended area where a vehicle strikes the earth. A missile aimed at an aerial target and hitting same is not to be regarded as having impacted.

13. In Flight Time: The total elapsed time from launch to an event sequence of a vehicle.

14. Motor Tail-Off Phenomena: The characteristics of a flight vehicle during the last instants of motor burning where the thrust dies down to zero.

15. Real Time: Actual flight time measured from launch (zero) to impact, as distinguished from hypothetical time in flight simulation studies.

16. Overland Operations: Any vehicle flight whether missile, rocket, or nonpiloted drone aircraft which flies over areas not under the control of the established missile range responsible for the operation.

17. Safety Criteria: That set of conditions which imposes restraints upon a vehicle in flight and which are implemented by devices such as flight termination systems.

18. Sensitive Areas: Those areas within the confines of an established missile range where there are clustered groups of personnel involved either in administration or in testing.

19. Wind Pointed: A vehicle which is aimed by launcher pointing only, and generally aimed to correct for the vehicle's behavior under predicted wind conditions.

20. Wind Sensitive: The deviations expected of a vehicle under given wind conditions. Wind pointed vehicles are the most wind sensitive. Guided vehicles may be corrected in flight for wind conditions, rendering these vehicles relatively wind insensitive.

21. x-Distance: The distance along the earth's surface from the projected point of termination onto the earth to the point of intersection of the termination curve with the earth. See Figure 1.

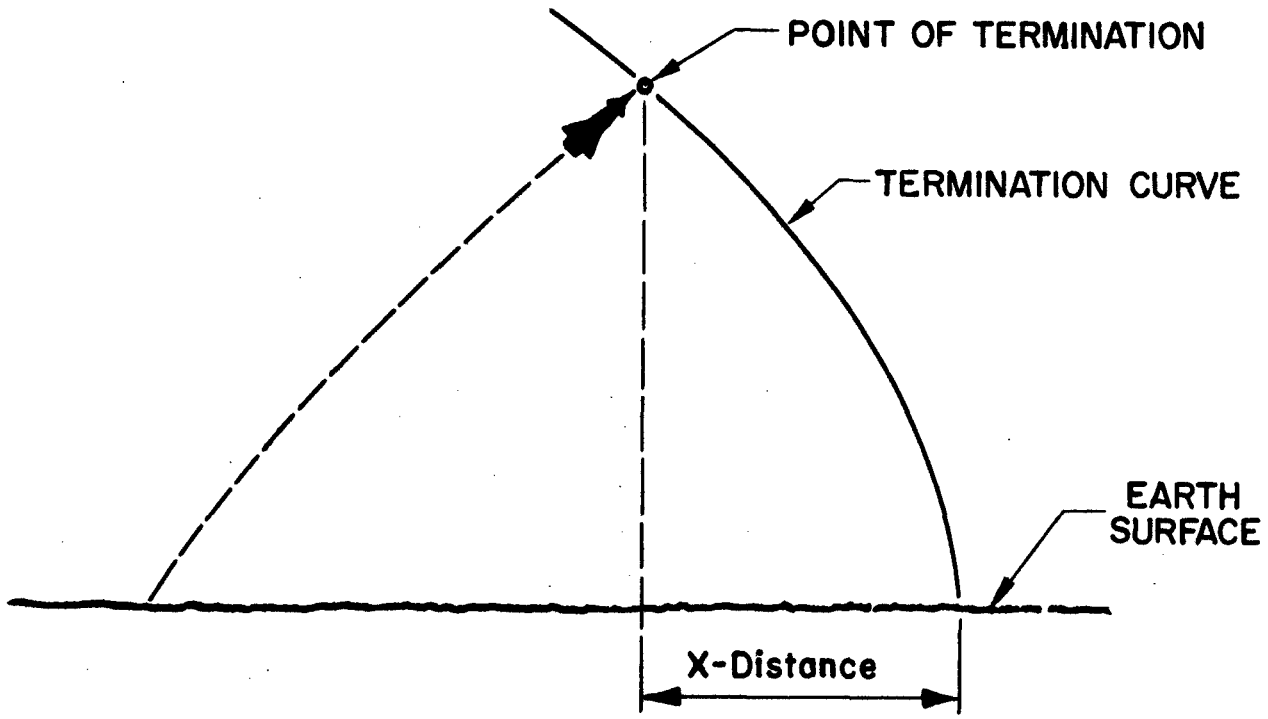

Figure 1 One Example of X-Distance

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